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Soil pH, electrical conductivity values and roadside leaf sodium concentration at three sites in central Poland

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Abstract: Sodium chloride is the most often used chemical to melt ice and snow on the roads and has negative effects on the roadside environment. The main is soil erosion, changes in mineral composition of the soil and negative impact of the growth of trees. This study described differences in electrical conductivity values in soil with increasing distance from the road. Leaf sodium contents in roadside trees have been determined to assess the uptake of this element by plants. Soil samples for EC (electrical conductivity) determination were collected in the spring and autumn 2009 and 2010 from the roadside environment every 1m started at 2m to 11m from the road edge, and every year at the same place. Leaf sample for sodium content were collected in the end of August 2009 and 2010 from Acer platanoides, Acer pseudoplatanus, Tilia cordata and Fraxinus excelsior, every year at the same trees. For comparison, samples of the leaves were also collected from trees grown in the park in Skiernewice, were no salting during the winters is provided. The composition of roadside salinity varies, mostly according to the roads, but generally, at the studied roads, the EC of the soil solution followed an exponential-like decrease with distance from the road curb, reaching background levels at 7 to 10 m distance. The exponential-like EC decrease seems to be strongly slowed at 5 m distance from the road curb. Very important information is that the level of EC in the upper layer of the soil during the season decreases rapidly. Trees grown on the roadside accumulated considerable amount of sodium ions in their leaves helping to neutralize the excess of sodium in soil. However, this had negative effect on their growth. Acer platanoides and Tilia corada uptake the greatest amount of sodium ions in comparison to the same species grown in the park. Less amount of sodium ion were noted in the leaf sample of Acer pseudoplatanus and Fraxinus excelsior. Soil salinity near the studied roads had any visual effect on the trees.

Additional key words: leaf sodium accumulation, soil electric conductivity, soil salinity, roadside trees, roadside environment

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Introduction

Sodicity-induced soil degradation is a major environmental constraint with severe negative impacts on agricultural productivity and sustainability in arid and semiarid regions. In Poland this problem is less common. However, only in December 2010 on roads and streets almost 200 thousand tons of NaCl (alone and mixed with sand) were applied to maintain safe driving conditions (press data of General Directorate of National Roads and Motorways in Poland). The use of NaCl results in increased soil salinity along the roads and is the main reason to damage roadside vegetation, and also contaminate of groundwater and
surface waters (Green and Cresser 2008). There are several factors regulating the airborne spread and deposition of salt, such as traffic characteristics, road type and surface condition, amount of salt application and weather conditions. Splash and spray emanate from the tyre-road interface, and are hence due to traffic. Splash is generally deposited in the proximity of the road, but salt spray can be transported further by wind (Blomqvist and Johansson 1999).

Road side soils and plants, especially trees and shrubs, are exposed for decades to road salt. As an important category of salt-affected soils, sodic soils exhibit unique structural problems as a result of certain physical processes (slaking, swelling, dispersion of clay, increase organic colloid mobility and alter the structure of the soil) and specific conditions like surface crusting (Shainberg and Letey 1984; Norrström and Bergstedt 2001; Qadir and Schubert 2002). In addition, changes in the proportions of soil solution and exchangeable ions lead to osmotic and ion-specific effects together with imbalances in plant nutrition, which may range from deficiencies of several nutrients to high levels of Na⁺ (Kaya et al. 2003; Marosz 2004; Marosz and Nowak 2008). Sodic and saline-sodic soils are generally described in terms of the relative amounts of Na⁺ in the soil solution or on the cation exchange complex, given the accompanying levels of salinity. Therefore, soil sodicity represents the combined effects of salinity is often measured by electrical conductivity of the soil (EC) or soluble Na⁺ concentration (Qadir et al. 2007).

Woody plants grown near the roads are force-fed by salt and this has a negative effect on their growth and decorative value (Marosz 2004). However, impact on roadside vegetation due to salt spray on aboveground tree parts or to salt uptake by roots also depends on where the salt is deposited, soil type and its ability to transport and retain water (Fostad and Pedersen 2000).

This research is focused on salinity and pH changes in the soil near the main roads in central Poland. Also sodium content in the leaves of trees that are grown along this roads is presented and discussed in earlier research leaded in control conditions.

**Material and methods**

**Characteristic of the studied road site.** The study site was located on three main roads in central Poland. First was the two line road between Zwołeń-Pulawy, about 10 km from Pulawy – 51°23’N 21°44’E. The site has an annual average daily traffic volume of about 3800 vehicles. The roadside soil at the site comprised of good sandy-loam soil (fine-grained). The trees begin at 8 m from the road (Fig. 1), while closer to the road the vegetation consists of grass that is cut once a year during the late summer. Trees are: *Acer pseudoplatanus, Tilia cordata*, and newly planted *Sorbus aucuparia* (unfortunately already dead). Second was located on the two line road nr 50 between Mszczenów and Grójec, about 15 km from Grójec – 51°54’N 20°42’E. The site has an annual average daily traffic volume of about 3500 vehicles (mostly trucks). The roadside soil at the site comprised wave-washed sandy-loam soil (medium-grained). The trees begin at 5 m from the road. Trees are: *Fraxinus excelsior, Tilia cordata*, (not often), few years ago new trees of *Sorbus aucuparia* were planted on the roadside but now all are dead. Third site was located on four line road nr 8 between Mszczonów and Rawa Mazowiecka, about 10 km from Rawa Mazowiecka – 51°50’N 20°21’E. The site has an annual average daily traffic volume of about 9500 vehicles. The roadside environment at the site comprised wave-washed sandy soil (medium-grained). The trees begin at 5 m from the road. Trees are: *Tilia cordata*, and *Acer platanoides* but this is not often seen.

On all sites closest to the roads, within 1 m distance, the natural soil layers are overlain by crushed rock from the road reinforcement layer. In this case that was impossible to take the sample from that site.

**Soil sampling.** Soil samples for EC (electrical conductivity) and pH determinations were taken in spring (2.04) and in the autumn (15.11) 2009 and 2010. Samples collection started at 2 m from the road curb and was ending at 12 m from road curb (Fig. 1 and 2). Each time then samples was taken from the three different depth of the soil: 10, 20 and 30 cm. EC and pH levels were measured using the multi-parametar analyzer (Eijkelkamp – Agrisearch Equipment, Netherlands), immediately after the samples were supply to the laboratory.

**Plant material.** Leaf sample from two trees (for each species) grown on the roadside were taken at the end of August every year of the study. For comparison of sodium accumulation, leaf sample were also collected from trees grown in Skierniewice Park and...
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these samples were treated as control. From one tree, two leaf samples were collected from the low part of
the crown. In total, the survey was intended for four
separate samples. Than samples were oven-dried at
70°C and treated with mixture of HNO₃. The concen-
tration of Na were measured using automatic absorp-
tion spectrophotometry (PU 9100X Philips).

Statistical analysis. The data for EC, pH and Na
leaf content were analyzed statistically with ANOVA
and are presented as means for two years. The exper-
iment was completely randomized with ten replicates
(every soil and leaves samples was treated as a repli-
cate). To establish significance of differences between
means Duncan’s Multiple Range Test was used.

Results

Salinity and pH changes in the soil

The composition of road salts varies, mostly ac-
cording to the roads, but generally, at the studied
roads, the EC of the soil solution followed an exponen-
tial-like decrease with distance from the road
curb, reaching background levels at 7 to 10 m dis-
tance. The exponential-like EC decrease seems to be
slowed at 5 m distance (Fig. 4–6). This might be the
effect of the road-parallel trench (Fig. 1 and 2), which
collects runoff water and dissolved salts.

The lowest level of EC in the soil was recorded in
samples taken from the roadside of the road
Zwoleń-Pulway. At a depth of 10 cm, electrical con-
ductivity in spring 2010 was 269 mS cm⁻¹. However,
the level of salinity increased with depth of soil sam-
pling, so that at a depth of 30 cm EC of the soil
reached 300 mS cm⁻¹. Very important information is
that the level of EC in the soil during the season de-
creases rapidly and in autumn 2010 the EC of soil so-
lution at depth of 10 cm in the vicinity of the road
(2–5 m from the road curb) was 42 to 110 mS cm⁻¹
lower than in the spring (Fig. 3). Therefore salt dur-
during the year was eluted to the deeper soil layers fairly
quickly, so that at depth of 30 cm salinity EC level
was higher in the autumn than in the spring (Fig. 3).
Soil EC along the two other roads with higher traffic
volume was higher and in the immediate vicinity of
the road at a depth of 10 cm contributed more than
300 mS cm⁻¹. Analysis of samples from the deeper lay-
ers of soil (20 and 30 cm) revealed that measurements
of EC in the spring did not differ significantly from
measurements made in the autumn (Fig. 4 and 5).

Analysis of soil pH shows that the use of salt for
snow removal from road surface significantly affects
the change of soil pH from a slightly acidic to alkaline.
Results from Table 1 shows that the highest soil pH is near the road curb, within 2 m distance. Then gradually decreases with increasing distance from the road and coincides exactly with the value of EC. These relationships were observed at all sites selecting for experiment (Table 1).

Leaf Na content

The results indicate that the use of sodium chloride for de-icing roadways affects of sodium ions downloading by the trees grown along the road and streets. The biggest amount of Na⁺ was accumulated in the leaves of *Tilia cordata* grown along the road no 12 and 50. Data from year 2009 and 2010 are similar. Trees of that species grown in Skierniewice city park had over four time less content of sodium ion than specimen from roadside environment (Table 2). Less amount of sodium ion was noted in *Acer platanoides*, but still significantly higher compared to trees grown in park. The lowest sodium accumulation was noted in the leaves of *Acer pseudoplatanus* and *Fraxinus*

Table 1. pH of the soil at the experimental site along the three road in central Poland, soil samples from 10 cm depth

<table>
<thead>
<tr>
<th>Localization/Road</th>
<th>Distance of the road curb (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Rawa Mazowiecka–Mszczonów</td>
<td>8.51d</td>
</tr>
<tr>
<td>Zwoleń–Puławy</td>
<td>8.53d</td>
</tr>
<tr>
<td>Gójec–Mszczonów</td>
<td>8.62e</td>
</tr>
</tbody>
</table>

*means followed with the same letter within the same road number do not differ significantly according to Duncans Multile Rate test at p = 0.05.
**Table 2. Sodium content in the leaves of mature trees grown on the roadside environment along the three road in central Poland (mg kg$^{-1}$ d.w.)**

<table>
<thead>
<tr>
<th>Trees localization</th>
<th>Acer platanoides 2009</th>
<th>Acer pseudoplatanus 2009</th>
<th>Fraxinus excelsior 2009</th>
<th>Tilia cordata 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2010</td>
<td>2010</td>
<td>2010</td>
</tr>
<tr>
<td>Rawa Mazowiecka- Mszczonów</td>
<td>–</td>
<td>0.46b</td>
<td>0.57c</td>
<td>0.33b</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>0.48b</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Zwoleń-Puławy</td>
<td>0.93b*</td>
<td>1.15b</td>
<td>0.32ab</td>
<td>0.39b</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.63b</td>
</tr>
<tr>
<td>Gójec-Mszczonów</td>
<td>1.18b</td>
<td>1.29b</td>
<td>–</td>
<td>0.56c</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.62c</td>
</tr>
<tr>
<td>Control Skierniewice Park</td>
<td>0.15a</td>
<td>0.22a</td>
<td>0.23ab</td>
<td>0.25a</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.16a</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.12a</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.42a</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.37a</td>
</tr>
</tbody>
</table>

**Means followed with the same letter within the same year and the species do not differ significantly according to Dun’s Multiple Range test at p = 0.05.**

**Table 2. Sodium content in the leaves of mature trees grown on the roadside environment along the three road in central Poland (mg kg$^{-1}$ d.w.)**

**Discussion**

The roadside environment is very heterogeneous and contains various soil and vegetation types within a short distance. Therefore comparing the three locations very distant from each other might be confusing. Norrström and Jacks (1998) found that road salt application had led to a Na saturation of up to 27% at the exchange complex of roadside soils, which in turn had significant impacts on soil colloidal behavior and heavy metal mobility. In the presented experiment is clearly shown that salinity rapidly decreases with distance from the road. This confirmed by other authors. Lundmark and Jansson (2008) underlined that differences with distance from the road were clearly shown in all measurements even with the soil temperature during the winter period which was generally lower closest to the road and showed less fluctuation compared with the variation in soil temperature in the forest soil. The first meters from the road received a high amount of salt deposition, snow from plugging and road runoff. This is also the region of highest uncertainty, both due to the complex situation and due to lack of deposition measurements close to the road. The redistribution of sodium chloride in both soil and snow is difficult to capture in both observations and modeling in this complex environment close to the road. There were no significant differences between the soil EC measurements at 2 and 3, 4, and 5 m that could confirm the difference in salt deposition (Lundmark and Jansson 2008). Results presented by Cunningham et al. (2008) support hypothesis that salt cations would show accumulation near impervious surfaces and decline with distance. Among all samples, Na$^{+}$ and Mg$^{2+}$ levels were higher near paved and road surfaces than far from them. The composition of road salts varies, but generally NaCl constitutes the main ingredient. At the studied highway, the NH$_4$NO$_3$-extractable Na contents followed an exponential-like decrease with distance from the road curb, reaching background levels at 5 to 10 m distance. Which is agreement with results presented in the article. The exponential-like Na decrease seems to be slowed at 3.7 m distance. This might be the effect of the road-parallel trench, which collects runoff water and dissolved salts. The trends observed for Na were confirmed by the electrical conductivity, which is a surrogate for the salt concentration in solution Lundmark and Jansson (2008). Soil pH is a very important factor that influences availability of micronutrients for plants. The optimal soil pH value for plant nutrition is 6.5 and if it exceeds 7.5, the uptake of important elements, such as Zn, P, Mn, Cu, and Fe, is hampered (Adams and Early 2004). The use of sodium chloride for road deicing resulted in increased soil alkalinity (Table 1). This is supported by Bach et al. (2007) where pH of soil under *Tilia × europaea ‘Pallida’* along main street in Częstochowa ranged from 7.4 to 8.6 and EC from 0.2 to 0.5 mS cm$^{-1}$.

McBean and Al-Nassri (1987) reported that deposition from the splash transport mechanism in the region close to the road can result in an uneven distribution of salt in the roadside environment. Splash could also to some extent be deposited on the hard shoulder, and the salt would then accompany the runoff water off the road. Salt spray can be transported longer distances by wind. Blomqvist and Johansson (1999) showed that some up to 100 m distance. However, it is not a significant amount of salt and it is quickly neutralized in the environment.

Sodium leaf content for trees from roadside environment is little higher than for this grown in the container, in laboratory experiment. Such differences are observed for *A. platanoides* and *T. cordata* grown...
under the highest sodium chloride treatment of EC solution 6.5 mS cm$^{-1}$ (Marosz i Nowak 2008). On plants grown in the container severe leaf burning and dropping were seen in comparison to specimens from natural site were no damage was noted. It must be said that the trees grown in containers were two years old seedlings and thus their response to salinity may be more pronounced compared with the mature trees from roadside habitats. However, Townsend (1980) observed severe leaf-injury on *Platanus orientalis* and *Cornus florida* grown along the highway. High Na$^+$ content in leaves connected with increasing soil or growing medium salinity is also reported by other authors. Mousavi et al. (2008) noted that olive trees grown under 160 mM of NaCl had accumulated more Na$^+$ than other macronutrients. Increasing concentration of Na ions in the leaves of *Quercus robur* was documented also by Sehmer et al. (1995). Also ornamental shrubs such a *Cotoneaster horizontalis* and *Cotoneaster ‘Ursynów’* downloaded significant amount of sodium under high soil salinity level (Marosz 2004). Lasted amount of Na$^+$ within respondent trees received *Acer pseudoplatanus* and *Fraxinus excelsior*, although significantly more than specimens from park.

**Conclusion**

Roadside soil pollution by sodium chloride is highly heterogeneous and – under the studied conditions (3500 -9500 vehicles per day) – most noticeable only in the immediate roadside zone, i.e. within 5 m from the road curb. Farther from the road the soil EC rapidly decreases. Trees of *Acer platanoides*, *A. pseudoplatanus*, *Fraxinus excelsior*, and *Tilia cordata* accumulated considerable amount of sodium ions in their leaves.

**References**


Fostad O., Pedersen, P.A. 2000. Container-grown tree seedling responses to sodium chloride appli-


